Field Test Program for Long-Term Operation of a COHPAC® System for Removing Mercury from Coal-Fired Flue Gas

Quarterly Technical Report
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DISCLAIMER

ABSTRACT

With the Nation's coal-burning utilities facing the possibility of tighter controls on mercury pollutants, the U.S. Department of Energy is funding projects that could offer power plant operators better ways to reduce these emissions at much lower costs. Sorbent injection technology represents one of the simplest and most mature approaches to controlling mercury emissions from coal-fired boilers. It involves injecting a solid material such as powdered activated carbon into the flue gas. The gas-phase mercury in the flue gas contacts the sorbent and attaches to its surface. The sorbent with the mercury attached is then collected by the existing particle control device along with the other solid material, primarily fly ash.

During 2001, ADA Environmental Solutions (ADA-ES) conducted a full-scale demonstration of sorbent-based mercury control technology at the Alabama Power E.C. Gaston Station (Wilsonville, Alabama). This unit burns a low-sulfur bituminous coal and uses a hot-side electrostatic precipitator (ESP) in combination with a Compact Hybrid Particulate Collector (COHPAC®) baghouse to collect fly ash. The majority of the fly ash is collected in the ESP with the residual being collected in the COHPAC® baghouse. Activated carbon was injected between the ESP and COHPAC® units to collect the mercury.

Short-term mercury removal levels in excess of 90% were achieved using the COHPAC® unit. The test also showed that activated carbon was effective in removing both forms of mercury–elemental and oxidized. However, a great deal of additional testing is required to further characterize the capabilities and limitations of this technology relative to use with baghouse systems such as COHPAC®. It is important to determine performance over an extended period of time to fully assess all operational parameters.

The project described in this report focuses on fully demonstrating sorbent injection technology at a coal-fired power generating plant that is equipped with a COHPAC® system. The overall objective is to evaluate the long-term effects of sorbent injection on mercury capture and COHPAC® performance. The work is being done on one-half of the gas stream at Alabama Power Company's Plant Gaston Unit 3 (nominally 135 MW). Data from the testing will be used to determine:

1. If sorbent injection into a high air-to-cloth ratio baghouse is a viable, long-term approach for mercury control; and
2. Design criteria and costs for new baghouse/sorbent injection systems that will use a similar, polishing baghouse (TOXECON™) approach.

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EXECUTIVE SUMMARY

ADA-ES began work on a Cooperative Agreement with the Department of Energy in September 2002 to fully evaluate activated carbon injection (ACI) in conjunction with a high-ratio baghouse (COHPAC®) for mercury control. The work is being conducted at Alabama Power Company's Plant Gaston. During the two-year project, a powdered ACI system will be installed and tested at the plant for a continuous one-year period. ADA-ES' responsibilities for managing the project include engineering, testing, economic analysis, and information transfer functions.

During the ninth reporting quarter, July through September 2004, progress on the project was made in the following areas:

- Held a team meeting on August 18, 2004.
- Prepared paper and presentation for DOE/EPA/EPRI/AWMA Mega Conference.
- Decommissioned test facility.
- Measured outlet particulate emissions.

INTRODUCTION

Cooperative Agreement No. DE-FC26-02NT41591 was awarded to ADA-ES to demonstrate activated carbon injection (ACI) technology on a coal-fired boiler equipped with a COHPAC® baghouse. Under the contract, ADA-ES is working in partnership with DOE/NETL, Alabama Power, and EPRI.

A detailed topical report will be prepared at the end of the test. Quarterly reports will be used to provide project overviews and technology transfer information.

Test Schedule

- Baseline Period 1 (March 28–April 21)
- Baseline Period 2 (May 28–June 26)
- Optimization Period 1 (April 21–May 27)
- Optimization Period 2 (June 26–July 18)
- Long-Term Test on Original Bags (July 19–November 25)
- Long-Term Test on High-Perm Bags (December 15–June 4)
- Alternative Carbon Tests (June 7–July 2)

Team Members

This program is made possible by significant cost-share support from the following companies:

- Duke Power
- EPRI
- Southern Company and Alabama Power Company
- Hamon Research-Cottrell, Inc.
- Allegheny Power
- Ontario Power Generation
- TVA
- Duke Power
- Arch Coal, Inc.
- ADA-ES, Inc.

A group of highly qualified individuals and companies was assembled to implement this program. Project team members include:

- ADA-ES, Inc.
- Southern Research Institute
- Grubb Filtration Testing Services, Inc.
- Reaction Engineering International

EXPERIMENTAL

Activated Carbon Injection Equipment

The activated carbon injection equipment was installed, field-tested, and continued to operate through the ninth quarter of the project.

Mercury Analyzer

The mercury analyzer is operating and measuring total vapor-phase mercury at the inlet and outlet of the COHPAC® baghouse.

A full equipment description can be found in DOE Report No. 41591R03.

RESULTS AND DISCUSSION

Significant progress was made during this reporting period to meet the overall objective of demonstrating long-term performance of carbon injection for mercury control. The original test plan was adapted to the operating conditions at the host site. These changes were documented in Report No. 41591R04, but primarily consisted of extending the baseline and optimization tests and modifying the injection scheme. The test plan for this program has five primary tasks:

1. Design and install an activated carbon injection system capable of continuous operation for up to one year.
2. Install a mercury analyzer capable of long-term, continuous operation. This analyzer is referred to as a Semi-Continuous Emissions Monitor (S-CEM).
3. Evaluate the long-term performance of carbon injection upstream of COHPAC® for mercury control. This task has two separate test periods:
    a. The first test (up to six months) was conducted using the existing set of bags.
    b. The second test (up to six months) was conducted on a set of new bags made from advanced fabrics.
4. Perform short-term tests of alternative sorbents.
5. Document test procedures and results, and complete reporting and management requirements.

Tasks 1, 2, 3, and 4 have been completed. Task 5 is in progress.

High-Perm Bag Test (December 15–June 4)

New high-permeability (high-perm) bags were installed December 4–8, 2003. The primary differences in design between these bags and the original bags are denier (an indication of fiber diameter; 2.7 versus 7.0 denier) and permeability (nominally 30 versus 130 cfm/ft^2 @ 0.5" H_2O).

The final schedule for the high-perm bag test was:

- Baseline Tests: December 15–January 5
- Optimization Tests: January 6–February 11
- Long-Term Test: April 20–June 4

Baseline Tests (April 20–May 4)

Following the spring outage, measurements were made for a two-week period without carbon injection to establish the post-outage baseline condition. Performance during this period was discussed in the previous report. The summary graph from this period can be seen in Figure 1.

To illustrate the impact of inlet loading on native mercury removal, a comparison of the carbon content of the inlet mass loading and removal efficiency was made. Figure 2 shows an approximation of inlet carbon concentration and mercury removal over the same time period. Carbon loading was calculated by:

1. Estimating inlet total particulate loading from the output of the BHA Particle Analyzer;
2. Estimating percent carbon from on-site LOI measurements of COHPAC® hopper ash. Average LOI from hopper samples can be seen in Figure 1; and
3. Using flowrate measured upstream of the baghouse and recorded on the COHPAC® computer.

Keeping in mind that carbon concentration is an estimate, several interesting observations can be made from Figure 2:

- At native carbon concentrations above nominally 2 lbs/MMacf, mercury removal varies directly with carbon concentration;
- At native carbon concentrations less than 2 lbs/MMacf, mercury removal does not appear to vary with injection concentration. Comparing this performance to activated carbon performance, where 90% removal was obtained at injection concentrations >1 lb/MMacf, illustrates the difference in effectiveness between an activated and an "LOI" carbon for mercury control.

Activated Carbon Injection (May 4–June 4)

The final period of activated carbon injection with high-perm bags was completed on June 4. From May 4 through May 21, carbon injection followed control logic that was programmed to vary injection rate based on inlet loading. Table 1 presents the injection rates at different inlet mass loading conditions. On May 21, the system was set to inject continuously at 45 lbs/h (1.3 lbs/MMacf). On May 28, the carbon injection rate was increased to 55 lbs/h (1.6 lbs/MMacf).

Table 1. Activated carbon injection operating parameters.

Inlet Loading (gr/scf)	Inlet Loading (gr/acf)	Injection Concentration (lbs/MMacf)	Carbon Injection Rate (lbs/h)
<0.1	~0.07	1.0 or 1.2	30 or 35
<0.2	~0.14	0.6	20
>0.2	~0.14	0	0

Performance and operating data with carbon injection can be seen in Figure 3. The graphs show inlet and outlet mercury concentrations, carbon injection rate, mercury removal efficiency, mass loading into both Unit 3B and 3A baghouses, and pulse frequency for Unit 3B. Table 2 presents average mercury removal at different injection concentrations and Table 3 compares performance data obtained during the original (2.7-denier) and high-perm (7.0-denier) bag tests.

Analysis and Interpretation of Figure 3 and Tables 2 and 3

- Inlet mass loading was highly variable during the entire test. Between May 4 and May 21, when carbon injection rate was set to follow inlet loading, carbon injection rate varied between 0 and 30 lbs/h. Bag cleaning frequency increased to as high as 2.5 pulses/bag/hour and was often near 2.0 pulses/bag/hour.
- Average mercury removal from May 4 through May 21 at noon was 82%.
- Average mercury removal when the injection rate was held steady at 45 lbs/h (1.3 lbs/MMacf) was 92%, with a maximum hourly value of 98% and a minimum hourly value of 80%.
- Average mercury removal when the injection rate was held steady at 55 lbs/h (1.6 lbs/MMacf) was 91%, with a maximum hourly value of 98% and a minimum hourly value of 79%.
- The previous quarterly report included a table with average mercury removal at different injection rates. Table 2 presents these data again, plus the average mercury removal at 55 lbs/h, which was evaluated during this reporting period. Before the spring outage, mercury removal was held at greater than 90% at an injection rate of 35 lbs/h (1.1 lbs/MMacf). After the spring outage, it was difficult to maintain the same removal at the

same injection rate, so the injection rate was increased to 45 lbs/h (1.3 lbs/MMacf). The injection rate was then raised to 55 lbs/hour (1.6 lbs/MMacf). There was no measurable difference in average mercury removal between the two conditions.

- Table 3 compares performance between the original and high-perm bags with similar activated carbon injection rates. At 20 lbs/h (0.6 lbs/MMacf), mercury removal was virtually the same (86% versus 87%). The primary difference in performance was seen in the cleaning frequency required to maintain a target pressure drop <7.0 inches H_2O. With the original bags, which had been in service for over three years, the cleaning frequency was 3.8 pulses/bag/hour. Under similar inlet mass loading conditions, the cleaning frequency with the high-perm bags was 0.7 pulses/bag/hour.

Table 2. Average mercury removal with carbon injection (original and high-perm bag tests).

Carbon ID	Injection Rate (lbs/h)	Injection Concentration (lbs/MMacf)[a]	Removal Efficiency (%)
FGD	20	0.6	87
FGD	25	0.8	91
FGD	30	1.0	94
FGD	35	1.1	93
FGD	45	1.3	92
FGD	55	1.6	91

a. Injection concentration calculated at full load condition

Table 3. Performance comparison with 2.7- and 7.0-denier bags.

	2.7-denier	7.0-denier
Injection Rate (lbs/h)	20	20
Injection Concentration[a] (lbs/MMacf)	0.6	0.6
Mercury Removal (%)	86	87
Cleaning Frequency (pulses/bag/hour)	3.8	0.7
Duration (days)	20	6

a. Injection concentration calculated at full load condition

Ontario Hydro Mercury Testing (May 26–27)

Weston Solutions, Inc., conducted the third and final set of Ontario Hydro tests on May 26 and 27. These tests included simultaneous inlet and outlet measurements of speciated mercury following the Ontario Hydro method, multiple metals sampling at the outlet, and hydrogen chloride sampling at the inlet.

During the tests, the injection rate was set at 45 lbs/h (1.3 lbs/MMacf). Results from these tests can be seen in Table 4. Average inlet mercury concentration was 15.6 μg/Nm^3 (11.3 lbs/TBtu). There was minimal particulate phase, 43% oxidized, and 56% elemental mercury at the inlet. The average outlet mercury was 2.3 μg/Nm^3 (1.7 lbs/TBtu), with 43% in the particulate phase, 48% oxidized, and about 8% elemental. The average removal was 85%. For comparison, the results from testing in October on the original bags are shown in Table 5. The most notable difference between the two tests is in the particulate phase mercury numbers. In the earlier tests, a significant percentage of the inlet mercury was reported as particulate (44%), compared to <1% in these tests. This is especially peculiar because we know that the inlet mass loading was at least as high as it was during the first test and that when there is particulate on the filter during an Ontario Hydro test, the particulate usually scrubs the mercury causing a significant percentage of the mercury to be reported as particulate. After reviewing run sheets, samples, and laboratory analysis, there appears to be no reason to suspect these data.

The S-CEM data correlated well with the Ontario Hydro results. S-CEM measurements and Ontario Hydro measurements are shown together in Figure 4. The S-CEM only measures vapor phase mercury. The Ontario Hydro data points in Figure 4 are only the vapor phase portion of mercury (particulate phase mercury was subtracted from the total mercury concentration). Both methods showed a large increase in inlet mercury on May 27. Both methods also show about 92% removal of vapor phase mercury.

Table 4. Results from Ontario Hydro tests across the Unit 3B COHPAC® with activated carbon injection at 1.3 lbs/MMacf and high-perm bags – May 26 and 27, 2004 (all mercury measurements in (mg/Nm^3) and corrected to 3% O_2).

	Particulate (μg/Nm^3)[1]	Oxidized (μg/Nm^3)[1]	Elemental (μg/Nm^3)[1]	Total (μg/Nm^3)[1]	S-CEM[2] Comparison
COHPAC® Inlet	**0.07**	**6.7**	**8.8**	**15.6**	***9.9–18.0***
COHPAC® Outlet	**1.0**	**1.1**	**0.18**	**2.3**[3]	***0.6–2.0***
Removal Efficiency	**-1,328%**	**83%**	**98%**	**85%**	***~92%***

1. Normal conditions = 32°F
2. S-CEM only measures vapor phase mercury
3. 2.3 μg/Nm^3 = 1.7 lbs/TBtu

Table 5. Results from Ontario Hydro tests across the Unit 3B COHPAC® with activated carbon injection at 0.6 lbs/MMacf and original bags – October 8 and 9, 2003 (all mercury measurements in (mg/Nm^3) and corrected to 3% O_2).

	Particulate (μg/Nm^3)[1]	Oxidized (μg/Nm^3)[1]	Elemental (μg/Nm^3)[1]	Total (μg/Nm^3)[1]	S-CEM[2] Comparison
COHPAC® Inlet	**4.5**	**2.5**	**3.1**	**10.2**	***8.7–13.4***
COHPAC® Outlet	**0.6**	**1.3**	**0.3**	**2.0[3]**	***0.6–2.2***
Removal Efficiency	**86.7%**	**48.0%**	**91.0%**	**80.4%**	***83–95%***

1. Normal conditions = 32°F
2. S-CEM only measures vapor phase mercury
3. 2.0 μg/Nm^3 = 1.5 lbs/TBtu

Table 6. Results from Method 17 particulate emission tests with high-perm bags at the Unit 3B COHPAC® inlet in May 2004 and the Unit 3B COHPAC® outlet in September 2004.

Location/Test Dates	Run 1	Run 2	Run 3	Mean
Inlet/May 2004	0.241	0.064	0.003	0.103
Outlet/September 2004	0.035	0.022	0.015	0.024

Alternative Carbon Tests (June 7–July 2)

Evaluating carbons from different manufacturers was the final testing task and was included to broaden the options of suppliers and sorbents evaluated in this program. Eight different sorbents were tested. A summary of the sorbent provider, product name, projected bulk commercial pricing, and a brief product description can be found in Table 7. Three of the sorbents were evaluated over a several-day period. The other five sorbent tests lasted as long as necessary to feed out about 500 lbs of material. When possible, more than one feedrate was evaluated. Test results, presented in Table 8 and Figure 5, are discussed below.

Table 7. Alternative carbon product description.

Company	Product Name	Projected Price ($/lb)	Product Description
NORIT Americas	E3	$0.65	Enhanced FGD activated carbon designed for low-halogen flue gas
RWE	HOK Super	$0.35	Activated lignite
General Technologies	PC-800 (FJ045)	$0.34	PAC made from bituminous coal
Superior Adsorbents	Merqsorb	$0.40	PAC made from bituminous coal
CARBOCHEM	MGF-20	$0.15	Low-cost material
Donau	Desorex DX 400C	$0.34	
Southern Company	PSDF Ash	TBD	Ash from pilot scale gasifier
Southern Company	Proprietary mix	TBD	

Analysis and Interpretation of Table 8 and Figure 5

- Removal efficiency measured at each of the conditions tested is shown in Table 8. In most cases, the removal efficiency is shown with a “<” symbol before the value. This convention is used to indicate that this value was the highest removal efficiency measured during the test. Because these tests were short and conditions were not stable, this value is not necessarily the steady state value that would be achieved if longer testing was possible.
- Figure 5 graphically presents the data in Table 8. This graph also shows results from parametric tests conducted in the Phase I program in 2001.
- Additional detail on the suppliers will be included in the next quarterly report.

- The overall conclusions from these tests are:
  - Most standard, high-quality activated carbon performed similarly at this site;
  - The low-cost sorbent and ash-based sorbents were not very effective at removing mercury; and
  - Chemically enhanced sorbents do not appear to offer any benefits over standard activated carbons.

Table 8. Alternative carbon parametric test results.

Carbon ID	Injection Rate (lbs/h)	Injection Conc. (lbs/MMacf)	Removal Efficiency (%)
A	20	0.6	<60
A	28	0.8	<70
A	35	1.0	<75
A	20	1.8	90
A	28	1.8	93
A	35	1.8	93
B	60	1.7	<36
B	120	3.4	<48
C	55	1.5	<78
C	55	3.1	95
D	63	1.9	<79
E	55	1.6	<20
E	110	3.1	<20
F	56	1.6	<67
G	56	1.6	<80
H	55	1.6	<50

DECOMMISSIONING (JULY 2004)

Decommissioning of the test facility was completed in July 2004.

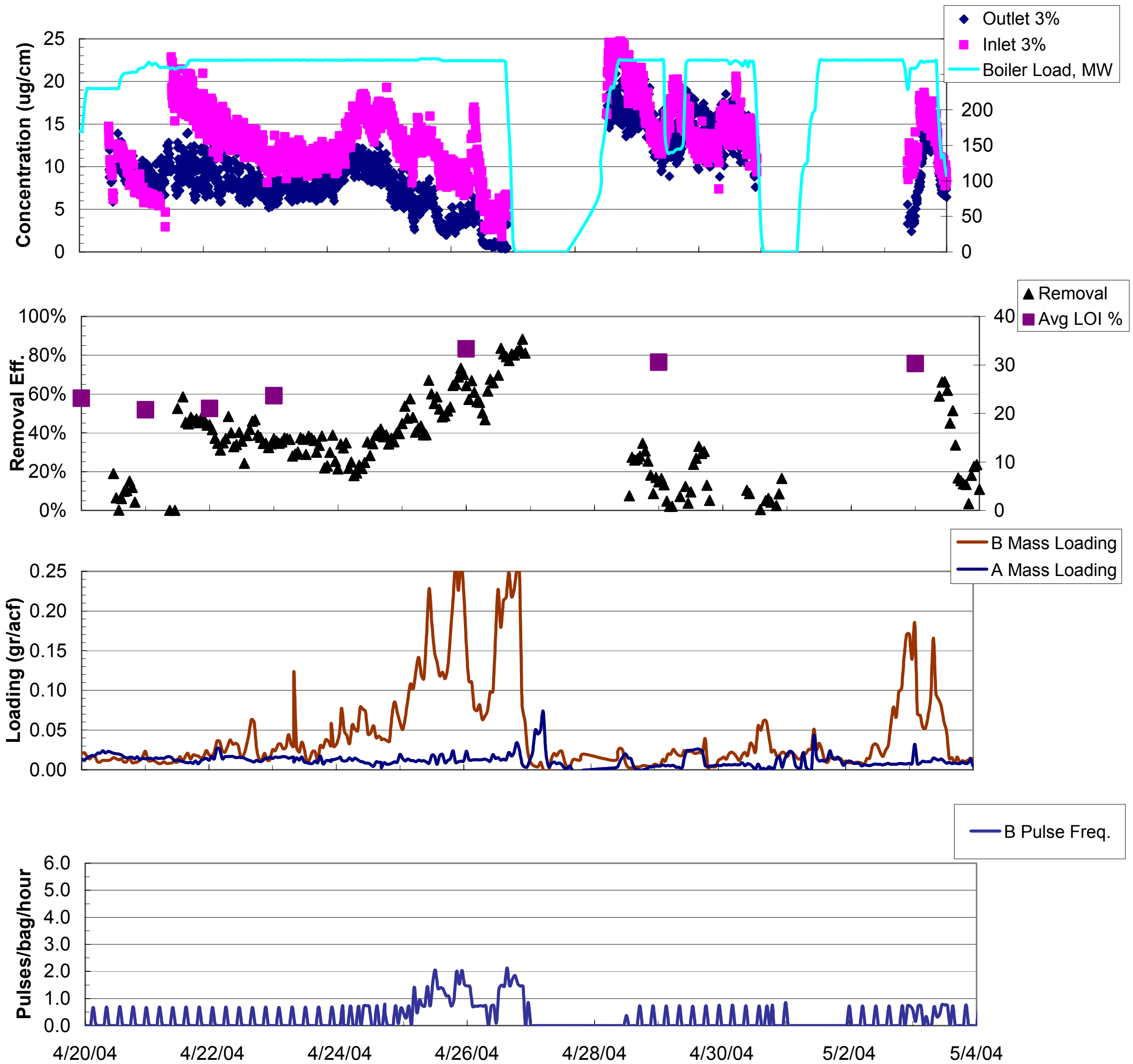

Figure 1. Inlet and outlet mercury concentrations, boiler load, removal efficiency, average hopper ash LOI, inlet mass loadings, and COHPAC® cleaning frequency from April 20, 2004, through May 4, 2004.

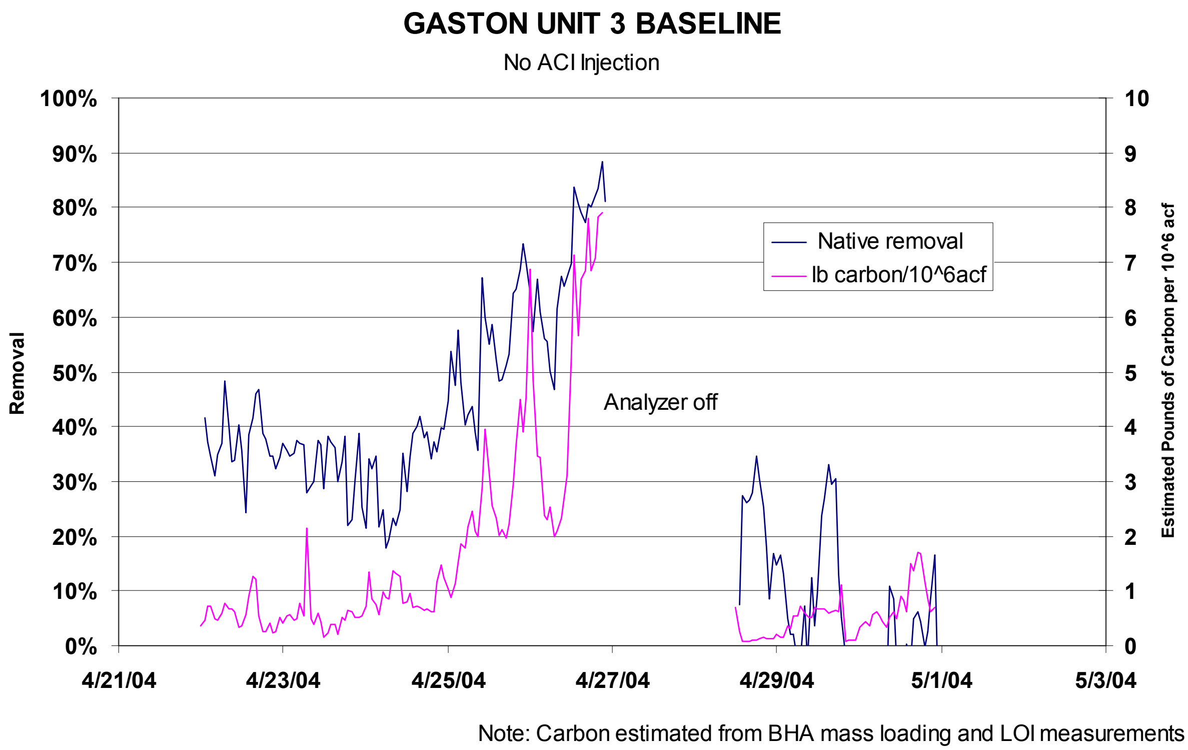

Figure 2. Comparison of inlet carbon loading and removal efficiency trends during baseline (no activated carbon injection) operation. Inlet carbon loading estimated using the BHA Particulate Monitor.

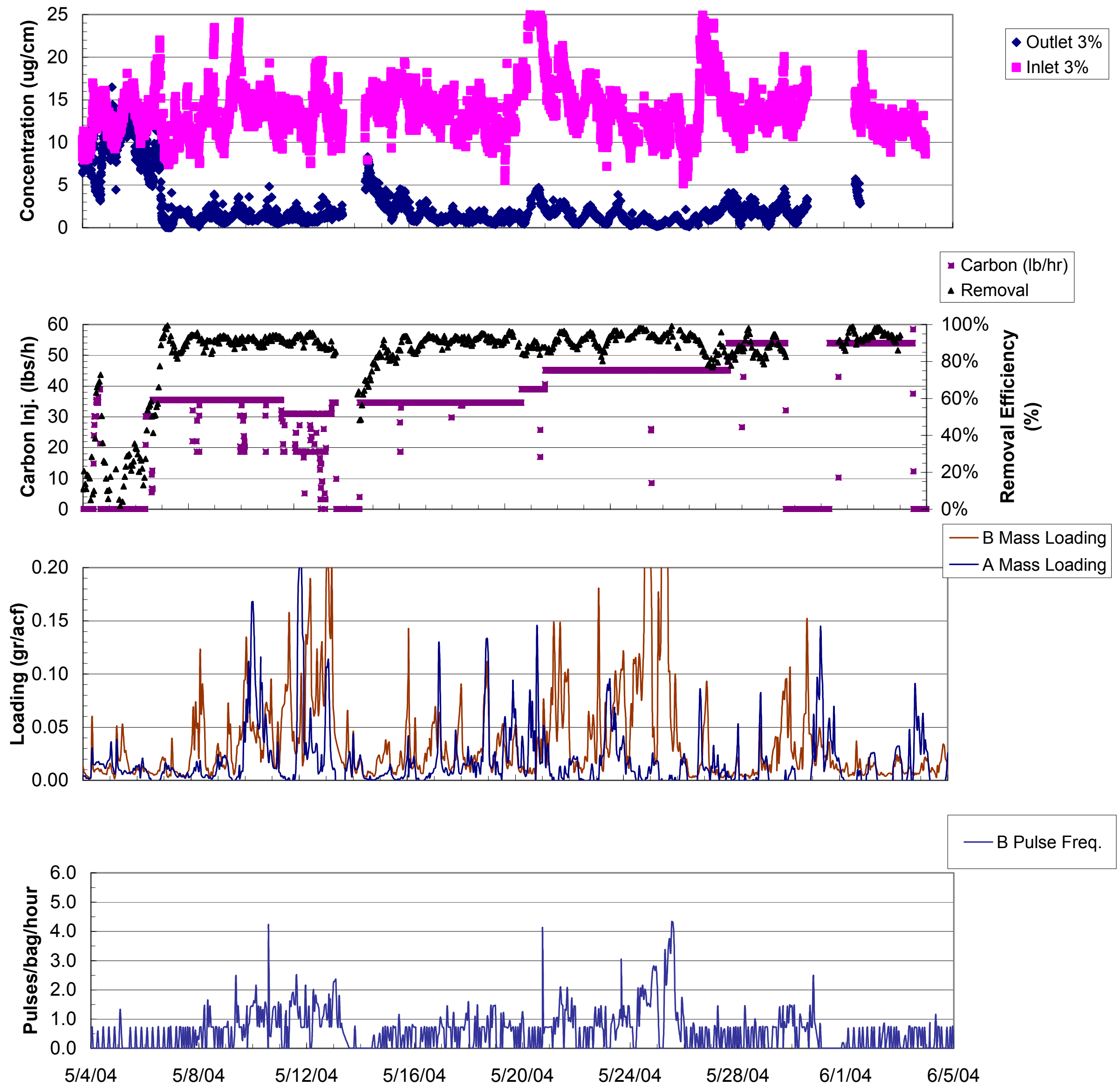

Figure 3. Inlet and outlet mercury concentrations, removal efficiency, activated carbon injection concentration, inlet mass loadings, and COHPAC® cleaning frequency from May 4, 2004, through June 4, 2004.

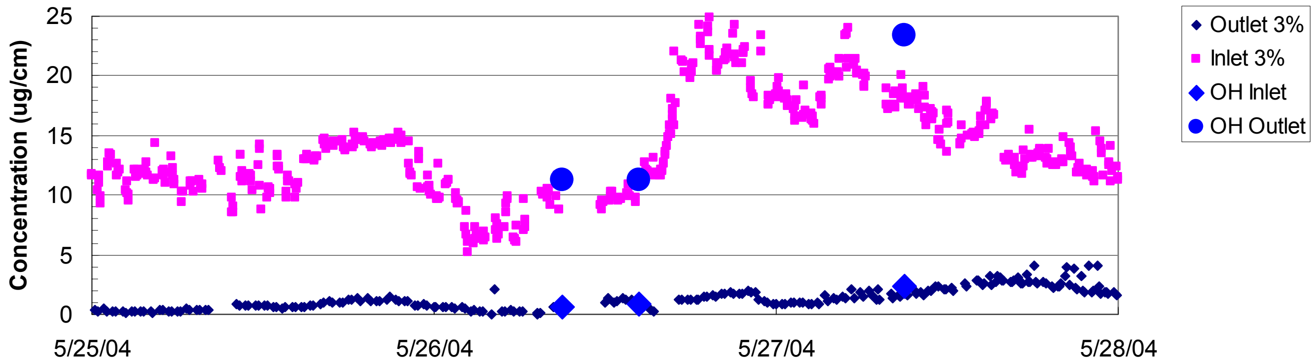

Figure 4. Inlet and outlet, vapor phase mercury concentrations measured with a S-CEM and the Ontario Hydro method on May 26 and 27, 2004.

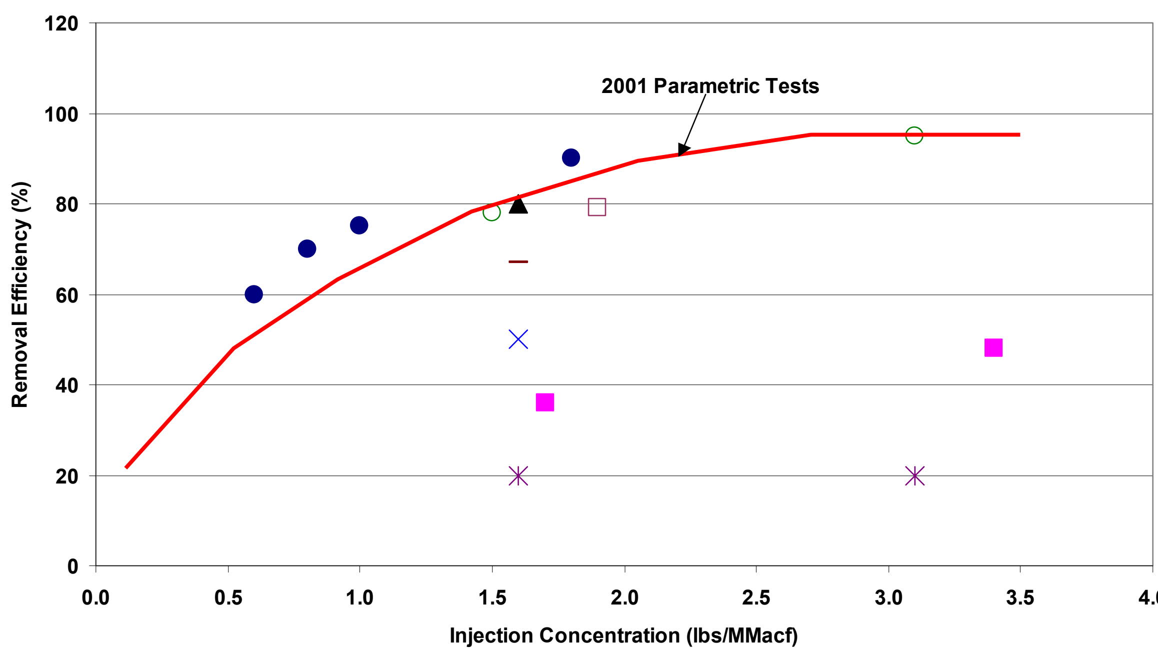

Figure 5. Results from parametric testing of alternative sorbents at Gaston Unit 3B COHPAC®, June 2004.